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KENTUCKY UNIV LEXINGTON DEPT OF STATISTICS  
COMPREHENSIVE RESEARCH ON THE RELIABILITY AND PERFORMANCE OF SY--ETC(U)  
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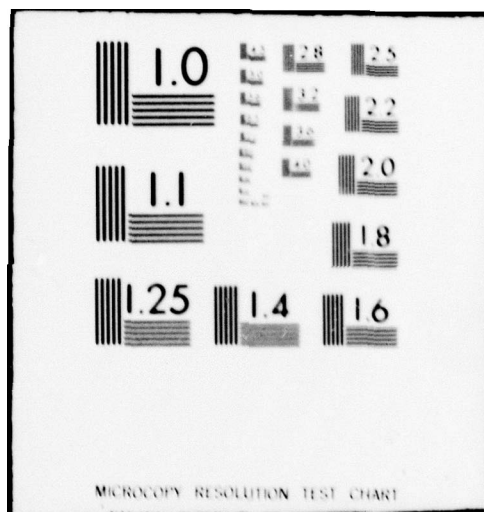
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The vast majority of reliability analyses assume that components and system are in either of two states: functioning or failed. This represents an oversimplification of the many real life situations in which both components and systems assume a variety of states ranging from perfect functioning to complete failure. In the present work a basic theory was developed for the study of systems of components in which any of a finite number of states may occur, representing at one extreme perfect functioning and			

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## 20. Abstract continued.

at the other extreme complete failure. The standard notion of Coherent Systems was extended to the new notion of a multistate coherent system. Deterministic and Probabilistic properties of such systems were obtained. Properties of length of time spent in the various states were investigated. A survey is made of the recent work performed by the relatively small number of researchers active in this area of Degradable (Multistate) Coherent systems. Such general theory will provide guidelines for deciding optimal policies for assembly and maintenance to improve level or performance of complex systems.

Characterizations of geometric distribution and discrete IFR (DFR) distributions using order statistics, and optimal replacement policies for some shock models were some of the results that were also obtained in the present work. Some of these results were mainly motivated by their relationship to multistate coherent systems.

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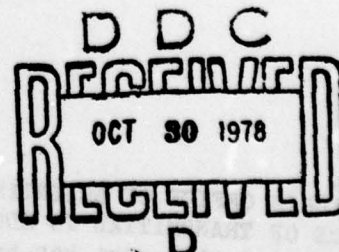
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Comprehensive Research on the Reliability  
and Performance of Systems and Components  
Assuming more than Two states.

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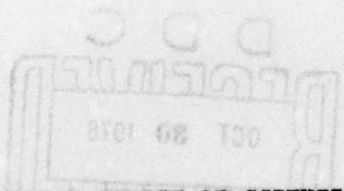
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Comprehensive Research on the Reliability  
and Performance of Systems and Components  
Assessing more than two orders

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## 1. Research Objectives and Achievements:

The vast majority of reliability analyses assume that components and system are in either of the two states: functioning or failed. In many situations one is capable of distinguishing between various "levels of performance" for both the system and its components. For such cases, the existing dichotomous model is a gross oversimplification of the real situation and models representing "multistate" systems and components are more adequate. Our main research objective under this grant has been to develop adequate models and comprehensive theory describing the performance and reliability of multistate systems and components similar to those existing for the two state case.

In a paper entitled "Multistate Coherent Systems" (with F. Proschan and J. Sethuraman) we developed adequate general model and theory for the case in which both systems and components may assume any of an ordered finite set of states, say  $0, 1, \dots, M$ , representing at one extreme ( $M$ ) perfect functioning and at the other extreme ( $0$ ) complete failure. We obtained a set of axioms extending the standard notion of a coherent system to the new notion of a multistate coherent system. We then used this concept as a unifying foundation for the study of the relationship between the performance of a system and the performance of the components in the system. A brief summary of this main paper will better describe its contents: Consider a system of  $n$  components. For each component and for the system itself, one can distinguish among say  $M + 1$  states representing successive levels of performance ranging from perfect functioning (level  $M$ ) down to complete failure (level  $0$ ). For component  $i$ ,  $x_i$  denotes the corresponding state or



performance level,  $i = 1, \dots, n$ ; the vector  $\underline{x} = (x_1, \dots, x_n)$  denotes the vector of states of components  $1, \dots, n$ . We assume that the state  $\phi$  of the system is a deterministic function of the states  $x_1, \dots, x_n$  of the components. Thus  $\phi = \phi(\underline{x})$ , where  $\underline{x}$  assumes its values in  $S^n$ ,  $S = \{0, 1, \dots, M\}$  and  $\phi$  assumes its values in  $S$ . We define a multistate coherent structure as a natural generalization of the standard concept of a binary coherent structure by requiring three reasonable conditions that  $\phi$  must satisfy.

We then obtained deterministic relationships between the performance of a system and the performance of its components; these relationships are natural generalizations of well-known results in the binary case. Thus we showed that the performance of a multistate coherent system is bounded below by the performance of a series system and bounded above by the performance of a parallel system. We also presented a decomposition identity useful in deriving inductive proofs and probabilistic properties for systems. Finally we generalized the practical result that redundancy at the component level is better than redundancy at the system level.

We then related in a probabilistic sense the performance of the system to the performance of its components, assumed statistically independent. The deterministic decomposition identity was then used to obtain a corresponding one for the performance function of the system. This decomposition identity was then used to show that system performance is a monotone increasing function of component performances. We also obtained useful bounds on system performance in terms of components performances.

Finally we considered multistate coherent system as operating over time. At time 0 the system and each of its components were assumed to be in state  $M$  (corresponding to perfect functioning). As time passed,



the performance level of components (and consequently of system) degraded to lower levels until finally level 0 (complete failure) was reached. We gave a definition of an NBU stochastic processes and proved the analogue of the NBU closure theorem using a new and simple characterization of the NBU property.

In another expository paper (with F. Proschan) a survey was made of the various treatments of multistate models. We briefly mentioned the earlier work but we concentrated on the more recent and more comprehensive treatments of multistate models performed by the relatively small number of researcher active in this important area of reliability. We compared between the various models. Such comparison showed that, in many aspects our model is more general and more comprehensive than the other treatments. We also showed by means of two examples that the theory of multistate reliability models provided useful and new treatment of some existing binary reliability models. This shows that not only do the multistate reliability models provide more realistic analyses of many real life situations, but they also permit to obtain a better understanding and a more efficient treatment of existing models in the two-state case. It is becoming apparent that such a general theory will provide guidelines for deciding optimal policies for assembly and maintenance to improve levels of performance of complex systems, including systems of direct importance to the Air Force such as airplanes, radar systems, computers, etc... .

Although the main theme of our research has been the multistate coherent system, we have also investigate some other problems and obtained useful results in various areas of reliability. The study of some of these problems have been motivated by their direct relationship to

multistate coherent system:

- (i) Extensions and generalizations of a simple model in structural reliability which has applications in various areas such as inventory depletion, urn sampling, ..., etc. . This simple model was studied by El-Newehi, Proschan and Sethuraman in an earlier paper. The model considered is that of a series-parallel system consisting of  $(K+1)$  subsystems called cut sets. We have investigated in the above mentioned paper the probability that the failure of such a system was due to the failure of a certain cut sets. We obtained bounds for such probability. We also investigated the life-length of the system (meaning the number of failing components that lead to the failure of the system) and obtained some of its properties. In the present work these results are extended to more general set ups. Also this model is shown to be related to a multistate coherent system.
- (ii) Characterizations of Geometric distribution and discrete IFR (DFR) distributions using order statistics were obtained in a paper with (Z. Govindarajulu). This result is an important and new step towards characterizing the various important classes of discrete life distributions.
- (iii) In a report (with P. Purdue) we investigated optimal replacement policies for systems subject to randomly occurring shocks. The models discussed included cumulative and maximum damage models with emphasis on systems with random thresholds.

2. List of papers and Technical Reports.

- a) Multistate Coherent Systems (with F. Proschan and J. Sethuraman)  
Journal of Applied Prob. (to appear)
- b) Characterizations of Geometric distribution and discrete IFR (DFR) distributions using order statistics (with Z. Govindarajulu).  
JSPI (to appear)
- c) A Note on Optimal Replacement Policies for Some Shock Models (with P. Purdue). University of Kentucky, Department of Statistics, Technical Report No. 121, 1978.
- d) Multistate Reliability Models. A Survey (with F. Proschan).  
Proceedings of the Fifth International Symposium on Multivariate Analysis. (to appear)
- e) Extensions and Generalizations of a Simple Model with Application in Structural Reliability. Extinction of Species, Inventory Depletion and Urn Sampling. A preliminary report in preparation (to be submitted to the Journal of "Mathematics of Operations Research").

3. Spoken Papers Presented at Meetings and Seminars.

- a) Multistate Coherent Systems: presented in a seminar at the Department of Applied Mathematics, McMaster University, Hamilton, Ontario, Canada.
- b) Characterization of Geometric distribution and discrete IFR (DFR) distributions using Order Statistics: presented at the Joint IMS-ASA Meetings held in Lexington, March 1978.
- c) A Note on Optimal Replacement Policies for Some Shock Models: Presented at the Joint TIMS/ORSA Meeting, New York City, May 1-3, 1978.